The Development of Analytical Techniques for Application in Condition Based Maintenance

D J Hodges & T J Nowell
Fuels & Lubricants Centre
Mechanical Science Sector
DERA Pyestock
Farnborough
Hampshire GU14 0LS
United Kingdom
+ 44 (0) 1252 374718
tjnowell@dera.gov.uk

S W Mahon & N Seaward
Multifunctional Materials
Mechanical Science Sector
DERA Farnborough
Hampshire GU14 0LX
United Kingdom
+ 44 (0) 1252 397418
swmahon@dera.gov.uk

A Curran
Propulsion Support Group Health
Block L
RAF Wyton
PO Box70
Huntingdon
Cambridgeshire PE17 2PY
United Kingdom
+ 44 (0) 1480 52451 extension 6387

Abstract: With increasingly tight financial constraints being placed on equipment operators, there is a continual need to both increase reliability and reduce the cost of ownership. To meet these requirements, maintenance managers must be in a position to make timely decisions about the serviceability of equipment that maximise availability for a given cycle cost.

Condition Based Maintenance (CBM) is the term given to a collection of methods that convey information about the mechanical condition of a system. Specifically CBM seeks to reduce maintenance and therefore cost, and to increase unit life, availability and operational safety.

It is important to appreciate that no single CBM technique can be relied upon to predict all possible failure modes and the decision as to which method or suite of methods to use depends heavily on the equipment being monitored. Whichever method is employed, it must provide confidence in the timely warning of impending malfunction, whilst minimizing the occurrence of unwarranted alerts.

CBM techniques can be divided into two main categories: Off-line, which involves sampling and subsequent analysis, and On-line, which monitor specific parameters of a system in "real time".

The Mechanical Sciences & Structures (MSS) group of the Defence Evaluation & Research Agency (DERA) is currently involved in the development of a number of both on and off-line techniques for military and civilian customers. The aim of this paper is to examine these methods and to discuss the intended applications within CBM.

Key Words: Condition Based Maintenance (CBM); On-line; Off-line; Mechanical Sciences & Structures (MSS); Defence Evaluation & Research Agency (DERA).

Introduction: The implementation of a Condition Based Maintenance (CBM) philosophy has the potential to significantly decrease maintenance costs for platforms [1]. But careful thought must be given as to how such a philosophy is adopted and what tools or techniques are available at the operators disposal. New CBM equipment is continually being offered to civil and military operators, but it should be realised that not every device available on the market is suited for universal application.

The Mechanical Sciences & Structures (MSS) group of the Defence Evaluation & Research Agency (DERA) is currently involved in the development of a number of CBM techniques for a variety of applications. The aim of this paper is to examine two of these methods, one on-line and the other an off-line package, to discuss the approach to designing and developing them.

Design and Development: The development of any CBM technology is fraught with difficulties. The designer must address a number of issues, such as

- What is the aim of the project?
- Is the final product intended for use on one specific piece of equipment or universal application?
- Will it compliment existing technology?
- What benefit will it provide the operator?

But designing and building CBM equipment that works on the test bench is only half the battle. A device may perform perfectly in the laboratory and fully meet its stated performance criteria, yet problems can occur in the "real" environment. It could also be that in the time taken to design, develop and test the device the original problem has been designed out of a system. In which case a lot of valuable resources have been wasted.

Any new device must complement other CBM techniques and provide information that is of value to the operator. Interpretation of results is vital; understanding data and relating it to the condition of a component is fundamental to any health-monitoring programme. The information an operator will wont to know is:

- Is the equipment fully serviceable?
- How severe is the problem?
- How many more operating hours before maintenance action is required?
- Can repair wait until a scheduled maintenance break?
- In extreme situations, such as an aircraft operating over water or in a hostile environment – is the vehicle capable of returning the crew to safety?

A problem with designing and building on-line systems for application in aircraft, particularly high-speed jets is that they have to operate in an extremely aggressive environment. Units must be compact and able to operate at elevated temperatures and withstand high levels of vibration. Compact design brings its own problems; electrical equipment generates heat and will require cooling. Another consideration is will the device work in real time or is data downloaded at the end of operation. Equipment operators do not want to be continually fed masses of information; in most cases a simple "Go/No Go" statement is sufficient. Placing of a device can also present difficulties, for example, an on-line debris monitor will need to be inserted into the lubrication system. It will have to be positioned so that a representative sample of the lubricant is tested, while not restricting the oil flow in any way.

Technology and resource focus is advancing towards the complete on-line Condition Monitoring System, attention is being focused on using advanced sensors integrated through algorithms and intelligent models to monitor, predict and manage aircraft health [2]. However, the total integration of available sensors into a single, compact tool is some way off. In the interim, it is vital that these various sensors are fully evaluated in the required operating environment, leading to the developed sensors being introduced as single items under a retrofit scenario. Although retro- fitting of condition monitoring equipment is inherently seen as expensive, they can provide indication of known or potential problems. The cost of fitting therefore has to be balanced against machine reliability/mission capability. The 'Holy Grail' is to have the complete Condition Monitoring System available at the design stage of a new machine.

The primary research focus should be on the improvement of diagnostic, failure mode isolation and severity assessment, and the development of prognostic, remaining useful life prediction. [3]. Considerations in designing a CBM device should be:

- Is there a particular failure mode that will occur?
- Will the technique monitor a parameter that is specific to the failure mode?
- Will the technique provide consistent indication under varying operating conditions?
- Are the measurements sufficiently accurate to give a reliable indication of potential failure?

The above points were taken into consideration during the development stages of the two CBM techniques discussed in this paper.

Piezoelectric Viscometer: Wear debris analysis is related to machine condition, not lubrication condition. The oil merely carries the information being analysed. Viscosity is the single most important property of the oil. It is the property that determines the fluid film thickness and the degree to which the component surfaces are separated. The successful combination of these techniques in an on-line monitoring system will provide the basis for real-time condition monitoring of mechanical systems. The Multifunctional Materials Group of the Mechanical Science Sector, DERA Farnborough has addressed this problem by developing an on-line viscometer package based on piezoelectric materials.

The condition of the oil in an engine is of paramount importance for efficient and maintenance free operation. The oil must perform a variety of functions. It must keep the engine clean by preventing the formation of acidic contaminants. It must lubricate parts to prevent wear and reduce friction, thus increasing engine power output. It must cool engine parts not accessible to the cooling system, and provide an airtight seal in the cylinder to maintain compression and combustion pressures. The critical nature of viscosity in engine operation means that it is desirable to be able to monitor *in-situ*. Thus, the development of an on-line viscometer would provide a powerful tool in the early diagnosis of engine health in terms of:

- Lubrication and prevention of wear
- Verification of correct oil mixture or fuel grade
- Fault detection e.g. fuel leakage
- Engine coolant
- Formation of air-tight seals
- Optimisation and extension of service intervals

A potential on-line viscometer must combine easy automation and small size with robustness and low unit cost. Traditional viscometers are based on measurements of the drag experienced by a body moving through a fluid. Such methods of measuring viscosity are often bulky, expensive and difficult to use.

In previous studies [4] it has been shown that the damping of a piezoelectric resonator is a potentially powerful method of measuring fluid viscosity. The current research addresses the development and validation of a low cost solid-state viscometer for a range of monograde and multigrade oil viscosities. The optimum sensor has been found to be a piezoelectric bimorph in which the oil viscosity is determined from the harmonic decay of the piezoelectric sensor after an initial deflection.

The benefits of an on-line viscometer have been widely recognised and in recent years a number of prototype solid-state viscometers have been proposed. These devices, which are based on quartz resonators, generally operate in the megahertz range. In engineering oils containing additives, the viscosity can become dependent on measurement frequency and it is desirable to have the capability to operate at a lower frequency to assess the magnitude of shear thinning effects. Additionally, the vibrational amplitude of quartz resonators is of the same order as the oil molecular and diffusional lengths, i.e., a few nanometers. In order to obtain a macroscopic estimate of viscosity it is necessary that the sensor employs larger amplitude oscillations. The flexural mode operation of the proposed bimorph sensor is attractive therefore, in that it utilises both a low frequency resonance and high bending strains.

The piezoelectric viscometer consists of a cantilevered beam vibrating in an oil reservoir (see Figure 1). The rate of decay of the natural resonance of the beam shows a qualitative relationship with the viscosity of the oil. In the derived mode of operation the bimorph is induced to bend by the application of a DC voltage, which causes the two sides of the beam to strain in opposition.

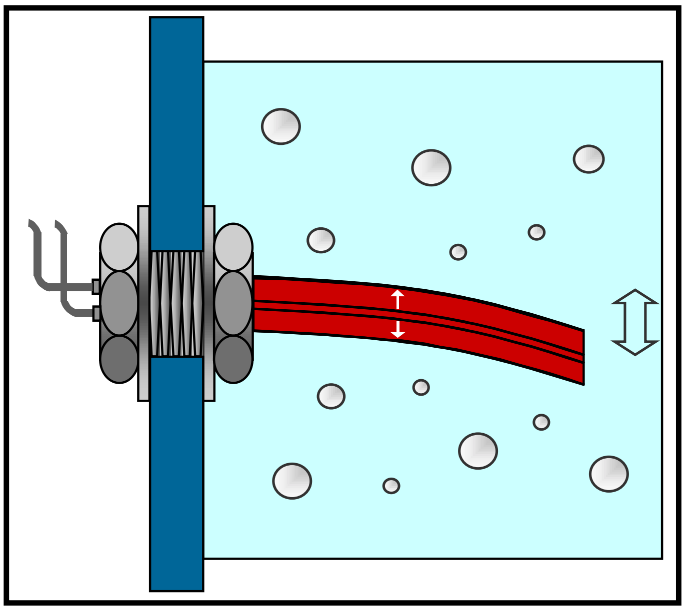

Figure 1: Schematic of piezoelectric sensor design.

Upon removal of the DC field the bimorph decays back to equilibrium at a natural frequency which is dependent on the geometry of the beam. As the piezoelectric bimorph oscillates it induces an AC voltage proportional to the damped harmonic motion (see Figure 2). The damped motion is dominated by the external force of the fluid in which it is immersed, with a minor contribution associated with the intrinsic damping of the beam. The more viscous the fluid, the larger the damping force and in turn, the greater decay of the oscillation.

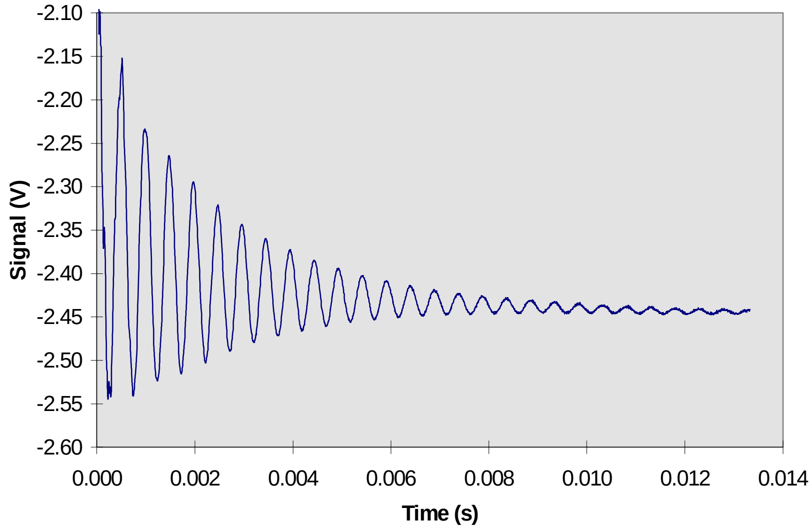

Figure 2: Decay of harmonic oscillations of piezoelectric sensor immersed in a mineral oil with a viscosity of ~ 20 cSt.

Theoretical analysis of the piezoelectric viscometer predicted that the loss tangent, tan δ, should directly relate to oil viscosity. This model was experimentally tested using a prototype probe where the initial deflection was produced by a DC voltage of 10 V applied for 50 ms. The loss tangent was calculated from the oscillatory decay of this probe in a wide range of mineral oils whose viscosity had previously been determined by established methods. The results obtained in a range of mineral oils indicated a high degree of correlation exists between viscosity and loss tangent, with the relationship being linear to within experimental error (see Figure 3).

Using the empirical calibration curve between loss tangent and viscosity, the viscometer was used to measure a suite of oils with a range of viscosities and densities, including monograde and multigrade mineral oil; used and unused oils and diesters (see Figure 4). For monograde mineral oils, the piezoelectric viscometer gave an accurate measurement of the oil viscosity. The value for multigrade oils was found to be consistently lower than that determined by established methods, this can readily be explained by noting that the frequency dependence of those oils that contain additives and modifiers. The piezoelectric viscometer operates at ~ 2 kHz, and it is at these frequencies that the viscosity begins to decrease. The degradation of both multi and monograde oils has been assessed by measuring new and used samples. From these results it can be seen that the piezoelectric viscometer can detect the same magnitude and direction of the changes in the viscosity as that determined by establish techniques.

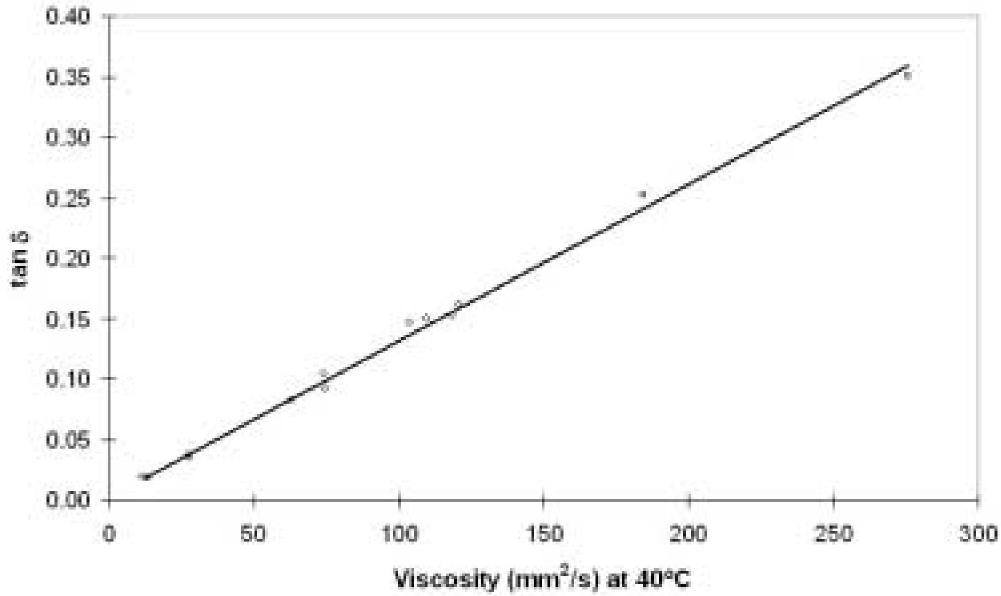

Figure 3: The correlation between the loss tangent of the transient decay of piezoelectric bimorph and the viscosity of monograde mineral oils.

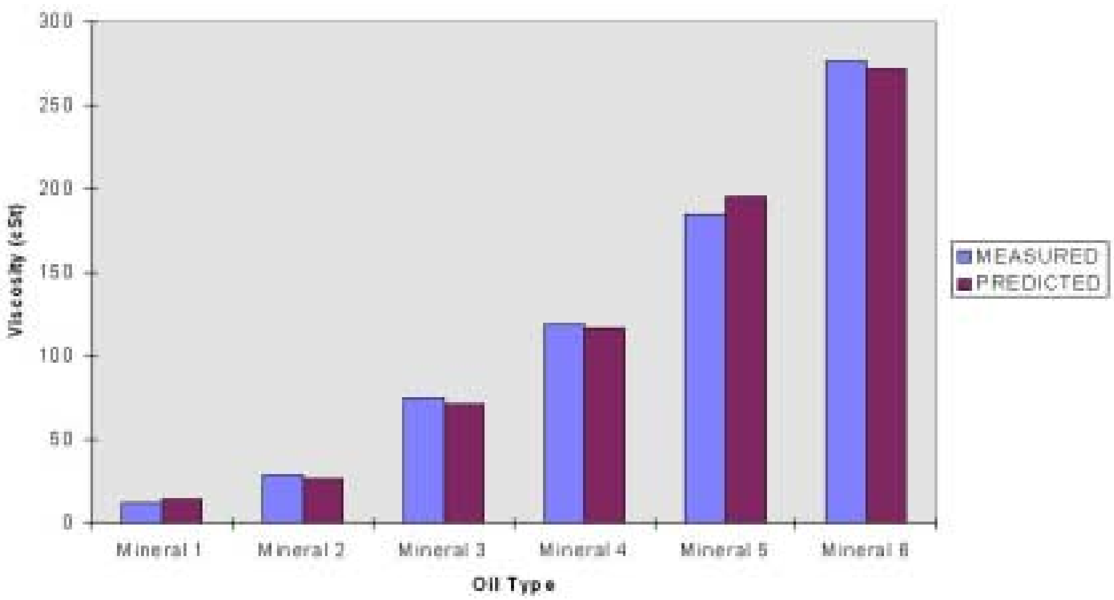

Figure 4: Comparison of viscosity determined using the piezoelectric viscometer and the "referee" method for a range of oil types

The work on development of the piezoelectric viscometer can be summarised as follows:

- Analytical models of the piezoelectric viscometer predicted a linear relationship between loss tangent and viscosity. This relationship has been experimentally verified and in room temperature trials the device gave accurate viscosity measurements in a range of oils.
- For monograde mineral oils the piezoelectric viscometer works well over a wide range of viscosities. The same relationship would appear to be valid for oils of different chemical compositions, e.g. diesters and polyalphaolefins.
- In multigrade oils the viscosity determined at 2 kHz by the piezoelectric device is consistently lower than that determined by the low frequency techniques. This is consistent with the frequency dependence of those mineral oils containing modifiers.
- The piezoelectric viscometer has been shown to detect oil degradation by changes in viscosity between new and used oils.
- The probe only requires small quantities of oil to produce a reliable viscosity measurement, thus minimising waste disposal and contamination.
- The device specification can be summarised as:

Range	1 to > 300 cSt
Accuracy	> 97.0 %
Repeatability	> 99.9 % (when operating in on-line mode)
Measurement Time	< 100 ms (This includes measurement and data analysis. No delay between successive readings)
Sample Size	0.1 to 1.0 ml
Sensor Size	10.0 x 1.5 x 0.5 mm
Operating Frequency	~2 kHz (dependent on sensor dimensions)
Temperature Range	0 to 150 ^{0}C
Power Supply	10 V DC

Wear Debris Classifier: Debris analysis is a powerful technique for non-destructive examination of oil-wetted components, the morphological characteristics of wear particulate giving detailed and important information about equipment health. The Royal Air Force operates a number of aircraft types where the routine analysis of wear particles generated within an aircraft engine or transmission is a primary condition monitoring tool. Trained personnel operating in specially equipped cells at Flying Unit level, known as Early Failure Detection Centres (EFDC) carry out the analysis.

Although the basic wear mechanisms across fleets are the same, each platform can produce characteristic wear patterns that may be used to indicate the incipient failure of a specific component. Currently within the RAF, there is no standard reference document or image libraries covering type specific failure patterns. Therefore, a need was identified for a wear debris classification system and a method for relating particle morphology with wear modes [5]. Placing the images within an interactive software package would present the operator with a structured approach to analysing the sample and indicate the onset of potential failures.

To this end the Mechanical Engineering Department, University of Wales Swansea (UWS), Fuels & Lubricants Centre, DERA MSS and the Propulsion Support Group Health at RAF Wyton have developed a wear debris classifier in a joint programme sponsored by the UK Ministry of Defence. This programme has resulted in producing the software tool known as SYCLOPS or SYstematic CLassification of Oil-wetted ParticleS. SYCLOPS has been designed to function as an expert system that will enable the user to make an objective assessment of the condition of a component. SYCLOPS has been developed to offer three levels of operation:

- Specialist operator - a reference gallery of images, classified by wear modes.
- Non-specialist operator - a guiding decision process using visual prompts to identify wear types within a sample.
- Novice operator - a tutorial to assist in the standardisation of wear particle descriptor terminology.

Laboratory studies into specific wear mechanisms and the generation of wear debris provided the foundation for a methodology for the classification of debris particles. By incorporating the classification data into a graphical user interface specifically developed to meet the requirements of the operator and an expert system based on a Baysian belief network, an objective debris classification system has been developed.

It was felt that it was important to try and understand the mechanisms involved in the production of specific types of debris and how these relate to conditions within an engine or gearbox. Under the sponsorship of the MoD Defence Procurement Agency, UWS undertook a study of the fundamentals of the generation of wear debris [6]. This entailed the production of debris particles under controlled conditions, simulating a variety of environments found in operational oil wetted systems. The main issues that were questioned in this programme were; what form do individual particles generated under specific wear modes take and what morphological attributes distinguish debris from one wear mode from another.

The wear modes routinely experienced in oil-wetted systems were considered and from these, suitable methods of producing wear debris under controlled conditions were identified. Initial testing was aimed at the generation of debris from abrasive, adhesive and pitting fatigue modes of wear. For these purposes the following test equipment was utilised:

- Four-Ball machine
- IAE gear rig
- Pin-On-Disc machine

During the course of this project a collaborative programme with NSK-RHP, Nottingham was established. This entailed NSK-RHP supplying UWS with debris generated as part of long term rolling element tests. This allowed for the opportunity to examine debris produced under load, speed, and temperature conditions that were more closely related to conditions encountered in practice. This form of testing also provided wear debris from bearing assemblies tested to destruction, making it possible to characterise the debris from initial running-in, transition and critical wear modes.

The main criteria chosen for the laboratory tests were materials, lubricant, load and speed. Although it is acknowledged that a number of other factors may influence the generation of debris, it was felt that limiting the number of variables would enable a more controlled test programme to be formulated. Applying these four factors, a test matrix was devised to emulate actual operating conditions, using a variety of lubricants and steels of varying hardness values and surface finishes. Collation of the data obtained from these tests, combined with a database of high quality images of the related wear debris, was used as the foundation for the development of the debris classification system [7].

Before formal development of the software platform for SYCLOPS began, it was deemed essential to clearly define the scope of the project to ensure that the final product was engineered to meet customer requirements. To this end, the Propulsion Training Flight, RAF Cosford and a number of EFDCs were visited to gather comments from potential ‘end users’. The EFDCs were selected so that a variety of platform types were represented, including fast jets, transport aircraft and helicopters. The findings of this survey were published as a User Requirements Document (URD) by the DERA Software Engineering Centre (SEC) and formed the basis for the formal development of the software platform [8].

During the User Requirements Analysis stage of the project, a limited functionality prototype of the classifier was used to elicit comments from potential users. This was initially based on a concept developed at UWS and, during the course of this study, was modified several times based on ideas suggested by EFDC operators. Having a prototype available to demonstrate the concept and functionality of the classification system was found to be invaluable. The ideas that were generated saved a great deal of time and effort in the later, formal development stages and this resulted in a user-friendly package. Through the process of successive refinement of user requirements, the final version of the SYCLOPS prototype (version ‘E’) embodied the look and partial functionality of the final system.

From the feedback gathered at the EFDCs, it became apparent that there was potential for three prime functions for SYCLOPS. These were identified as: -

- To assist all EFDC staff in the routine classification of wear debris particles
- To assist in the training of new EFDC staff in wear debris classification
- To provide a consistent source of reference material, in the form of images and technical information relating to wear debris

To meet these capabilities, the following three modes were defined: -

- **Classifier mode:** This mode would assist the operator in the task of wear debris classification (see Figure 5).
- **Tutorial:** This mode would enable new EFDC staff to become familiar with the task of wear debris classification.
- **Gallery:** This mode would provide easy access to a common database of wear particle images and related information.

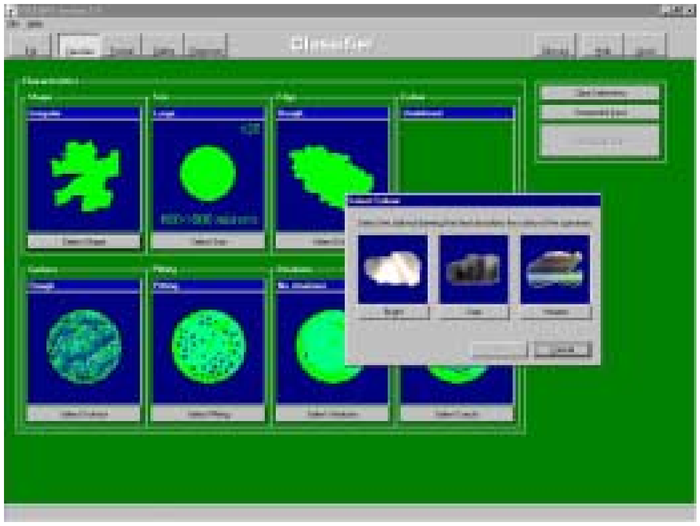

Figure 5: Screen shot of SYCLOPS Classifier page

In addition to these three main applications, an extensive glossary of terms and definitions was included. This is based on the RAF EFDC manual and serves to ensure that common terminology relating to wear debris analysis, would used by EFDC staff [9].

As potential users of SYCLOPS may have little Information Technology (IT) experience and may only occasionally use the system, it was considered particularly important that the interface be predictable and intuitive. To this end, the DERA Centre for Human Sciences (CHS) was approached to assess these aspects of version 'E' of the SYCLOPS prototype, with particular emphasis placed on ease of use, ease of learning and functionality.

The published findings from CHS were very encouraging from a design point of view [10]. The main conclusions of the report stated that full consideration had been given to the end user in terms of ease of use and that no substantial user interface problems had been identified in the evaluation. A few minor modifications were mooted; in particular the exaggeration of the stylised images in the Tutorial and Classifier modes and the further development of the Help facilities. These suggestions were noted and incorporated in the final version of SYCLOPS.

For the formal development of the SYCLOPS wear debris classifier, two key areas were identified as being essential to producing a fully functional system [11]. The first of these was the software platform, basing the structure of the graphical user interface (GUI) on the findings of the URD. This task was undertaken by DERA SEC. The second area relates to the decision-making function of the expert system. This work was conducted by UWS, based on data generated from the database of images compiled during the Generic Studies phase of the project.

The wear debris classification system developed by UWS employs a Baysian belief network as the software engine, performing the decision making function [12 & 13]. The belief network was built using the Norsys Netica software application. Netica is a comprehensive tool for working with Baysian belief networks and influence diagrams. It has the ability to create probabilistic expert systems and was used in this capacity for the diagnosis of wear particles.

The network is able to infer diagnosis by using probabilities. For example; what is the probability that a fatigue particle will be identified from an elongated shape, a rough edge, a smooth surface, bright colour, striations and pitting? Therefore, before the network can be used, base probabilities need to be set from known data. The known data can be fed into the network as a case file.

On completion of the development SYCLOPS Version 1.0 was evaluated at a number of RAF units. The principal objectives of trialing the software were:

- To assess the value of SYCLOPS as a training and diagnostic tool.
- To assess the user friendliness of the SYCLOPS software.

The choice of units for trialing was based on obtaining a wide selection of aircraft types and a full range in the experience of EFDC personnel. The intention of these trials was to demonstrate SYCLOPS applicability for use in RAF EFDCs as an effective method for performing objective wear debris analysis. The trial programme ran from 31 January 2000 to 31 March 2000, after which comments were submitted from each site.

The findings of the filed trials were very encouraging and SYCLOPS was very well received by EFDC personnel. In the main, criticism was very constructive and the majority of the suggested amendments will be included in Version 1.1 of the wear debris classifier.

The development of Version 1.0 of the SYCLOPS wear debris classification system, was based on generic wear debris generated in the laboratory. It is appreciated that debris particulate generated under these conditions may not relate directly to “real” debris. Therefore, the next phase of development of SYCLOPS will incorporate platform specific debris. By characterising historical debris records from engines and transmissions the data will enable the expansion of the capability of SYCLOPS. To achieve this, each platform Engine Authority will be approached and asked to identify specific EFD problems associated with power units or transmissions.

Summary: The two projects examined in this paper have been approached from two different directions and have proved to work equally well. This has resulted in the successful development of an on-line oil condition monitoring sensor and an off-line wear debris classifier package.

The viscometer has been developed from a foundation of research centred on analytical modeling and laboratory based trials. This has shown the validity of the piezoelectric viscometer, both in concept and operation. A prototype device has been successfully tested on oils with a wide range of chemical compositions and at varying stages of degradation. The development of the sensor offers the potential to monitor the condition of oil in engine sumps of military and civilian ships and aircraft.

The SYCLOPS wear debris classifier on the other hand, was developed as a result of consulting the end users. This was done to ensure that the package would meet the requirements of RAF EFDC staff and the results of the field trials indicate that this aim has been achieved. Although SYCLOPS has been developed for a military customer, the flexibility of the design means it could easily be adapted for use by civilian CBM operators.

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Tim Nowell
Fuels & Lubricants Centre
DERA Pyestock
&
Al Curran
Propulsion Support Group Health
RAF Wyton

DLO

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Objectives of Condition Based Maintenance

Safety

Is it safe to operate and for how long ?

Operational Requirements

Is the equipment available when and where required ?

Cost

Are all maintenance actions absolutely necessary ?

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CBM Techniques

All condition monitoring techniques should be viewed as complementary

Thought should be given to the best combination of methods to facilitate an effective health monitoring programme

When developing methodology or equipment, the final application must be carefully considered

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Development of Analytical Techniques

- On-line Viscometer

  In-situ lubricant analysis to enable continual assessment of engine health and to enable optimisation and extension of service intervals

- Wear Debris Classifier

  Objective analysis of wear particle morphology and relating this to wear modes within an engine or gearbox

Piezoelectric Viscometer

Develop On-line Viscometer Technology

- Compact design
- Low cost
- Mounting and clamping sensor
- Temperature range and cycling
- Sensor optimisation
- Sensor coatings

Operating Principles

The piezoelectric viscometer consists of a cantilevered beam vibrating in an oil reservoir

Application of a DC voltage cause the beam to bend

When the voltage is removed, the bimorph returns to equilibrium causing the two sides of the beam to strain in opposition

Operating Principles

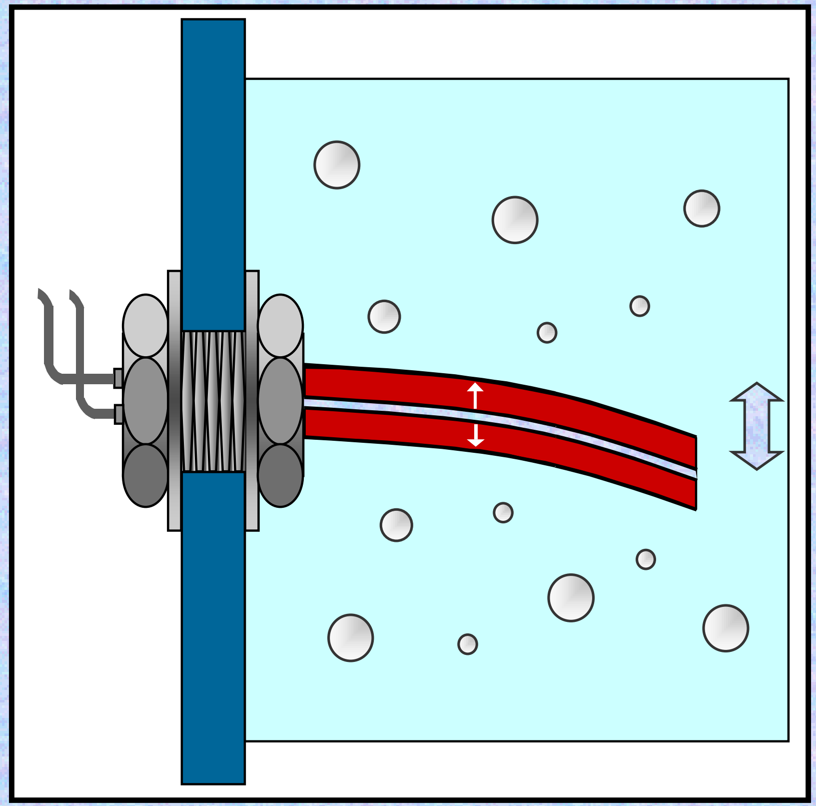
Oscillation of the piezoelectric bimorph induces an AC voltage proportional to the damped harmonic motion

The dampen motion is dominated by the external force of the oil

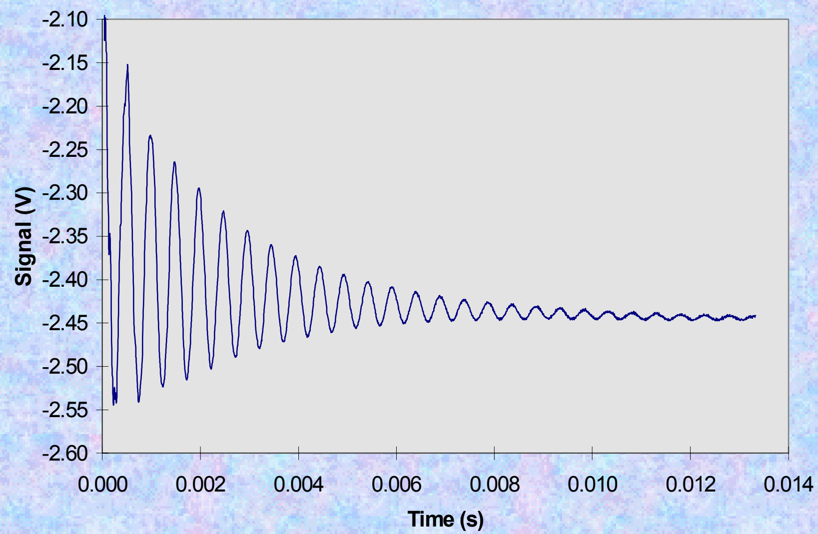
The more viscose the fluid the larger the damping force, and the more rapid the decay of the oscillation

Piezoelectric Viscometer

SENSOR



SIGNAL



$$V_n=V_0.\exp(-n.(\tan \delta)^{-1/2})$$

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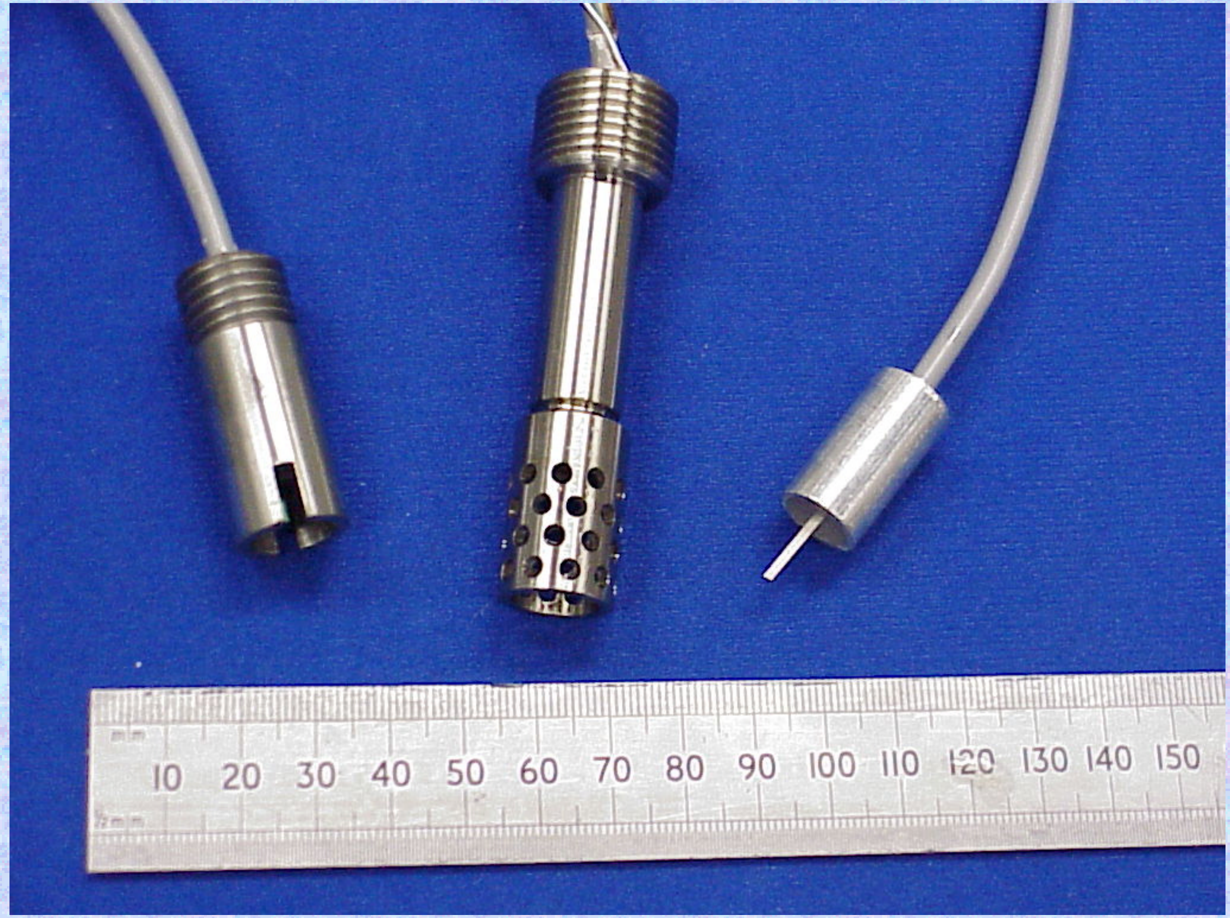
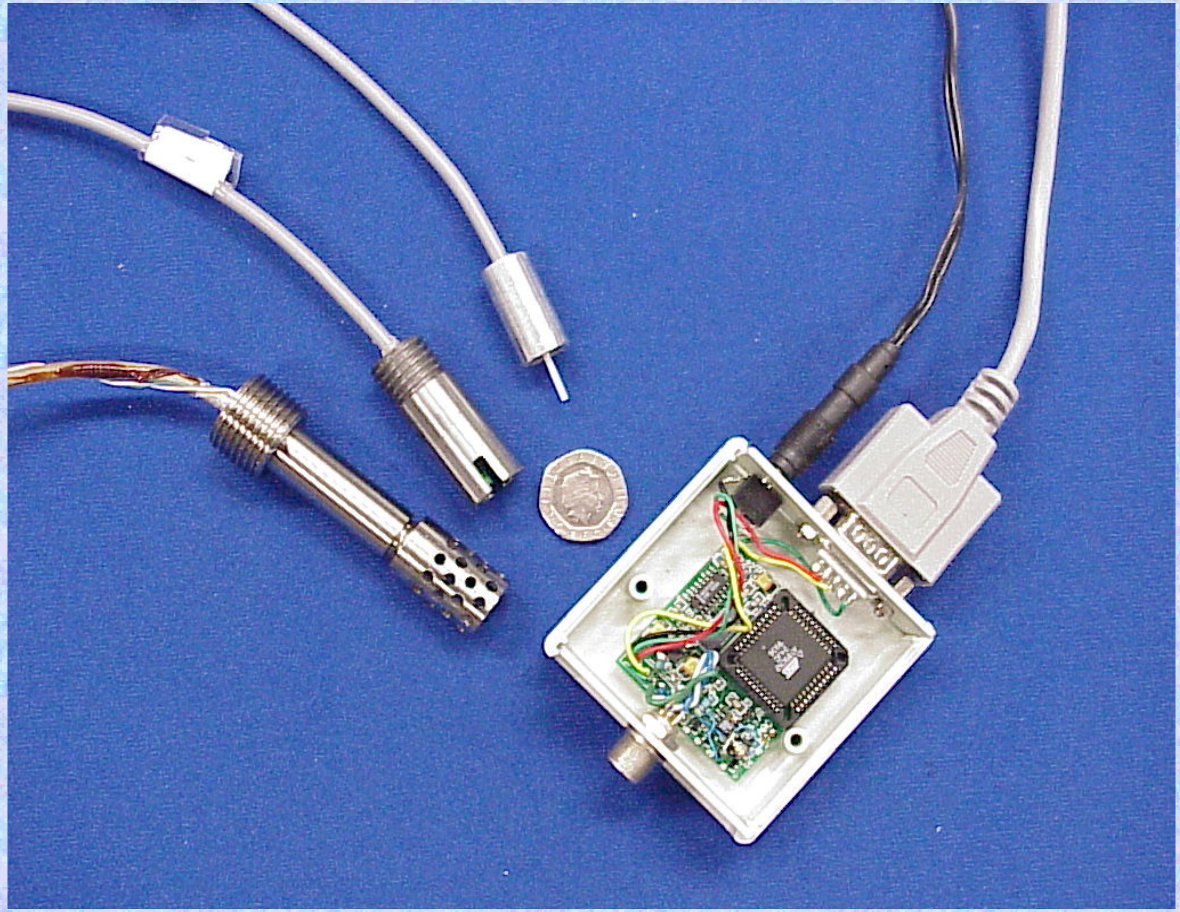
Sensor Design



Sensors packaged in a range of plastic and metal housings

Electronic Package



Electronics performs all analysis and processing

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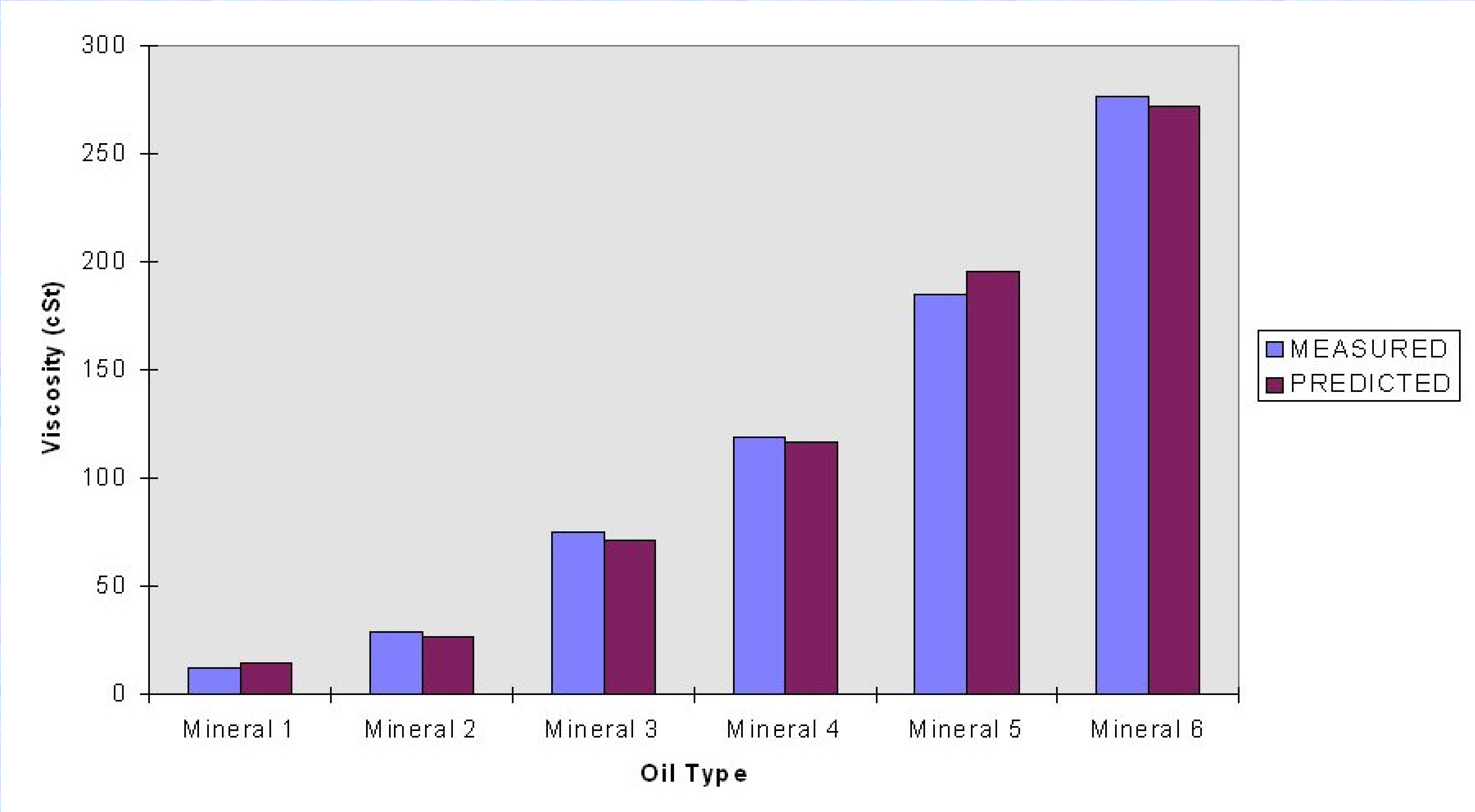
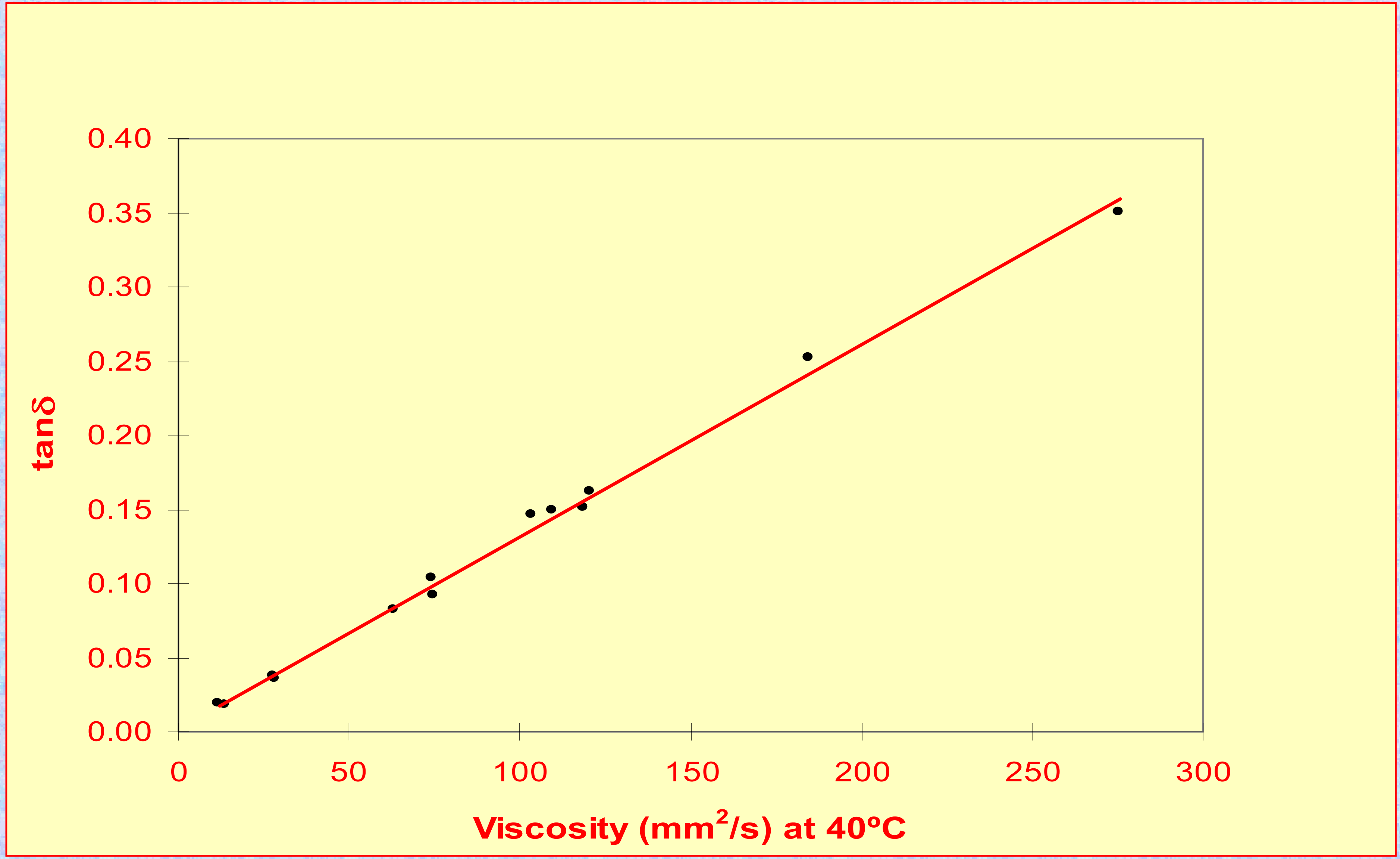


Comparison of viscosity determined using the piezoelectric viscometer and the “referee” method



Piezoelectric viscometer calibration for monograde oils at room temperature

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Sensor Specification

Range	2 - 700cST
Accuracy	< 0.5 %
Repeatability	< 100 ms
Sensor Size	10 x 1.5 x 0.5 mm
Fluid Sample Size	> 0.1 ml
Operating Frequency	~ 2 kHz
Temperature Range	non-freezing - 150^{o}C
Power Supply	mains/10 V DC

Benefits of Piezoelectric Viscometer

- Solid-state sensor
- Low cost
- Sound theoretical basis
- Compact design
- Small sample size
- High temperature operation
- Can measure viscosity in wide range of oils
- Able to detect degradation of oil

Further Development

- Design and development of miniaturised electronic hardware to eliminate PC processing and enable construction of a portable device

- Develop a passive vibration mount to allow sensor to operate in a high noise environment

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Wear Debris Classifier

- Provide RAF EFDC personnel an objective means to identify wear mechanisms within engines and gear boxes

- Develop a software based directory of all wear debris types encountered in oil washed systems

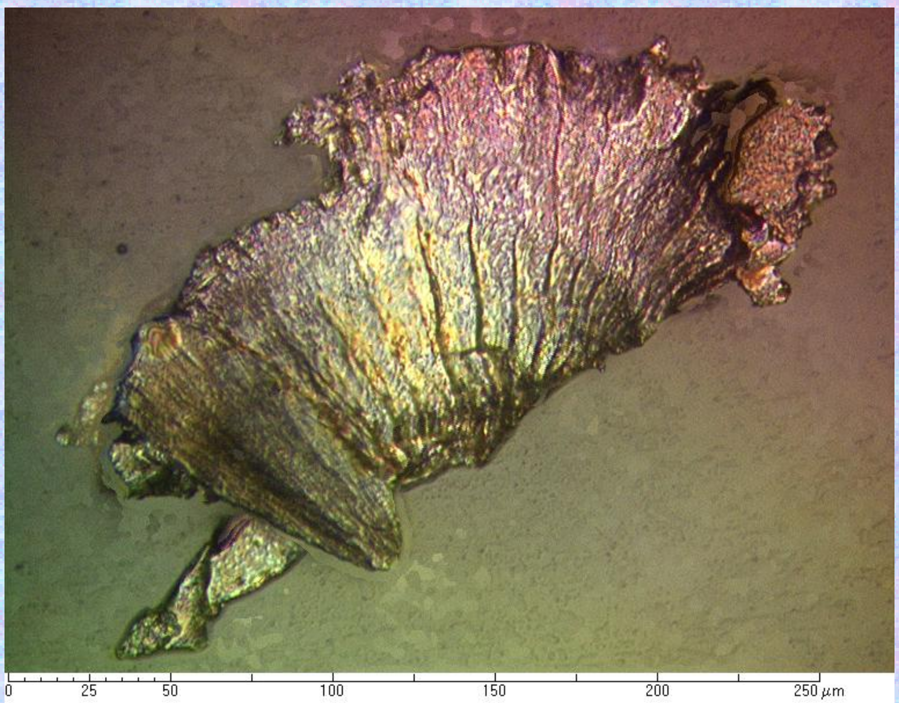
Debris Morphology and Wear Modes

Understanding the relationship between debris morphology, wear modes and relating it to a components health is fundamental to an effective Condition Monitoring programme

Wear Debris - Size, shape and quantity

Wear Modes - Benign, active or critical

Wear Debris Analysis



Pitting Fatigue Particle x400

The principal wear modes within an oil-wetted system produce characteristic wear debris. By learning to recognise the features of the wear particles, it is possible to make a quick and accurate assessment of a components condition

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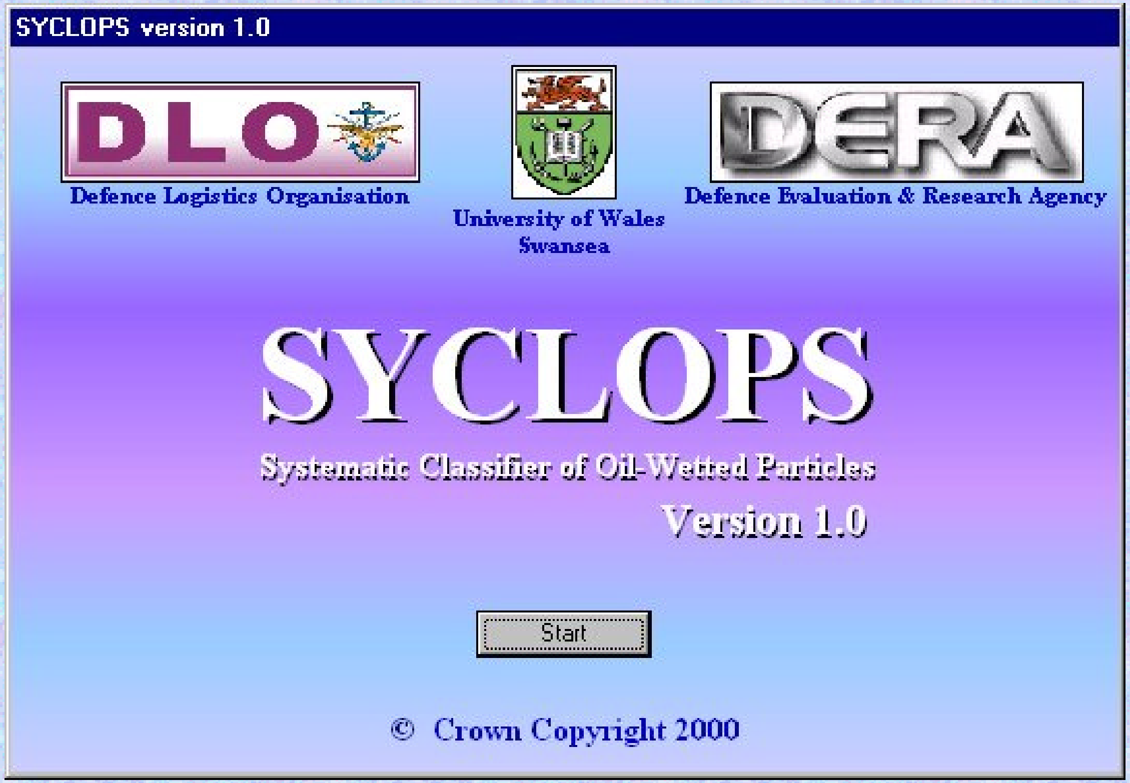
Primary Functions

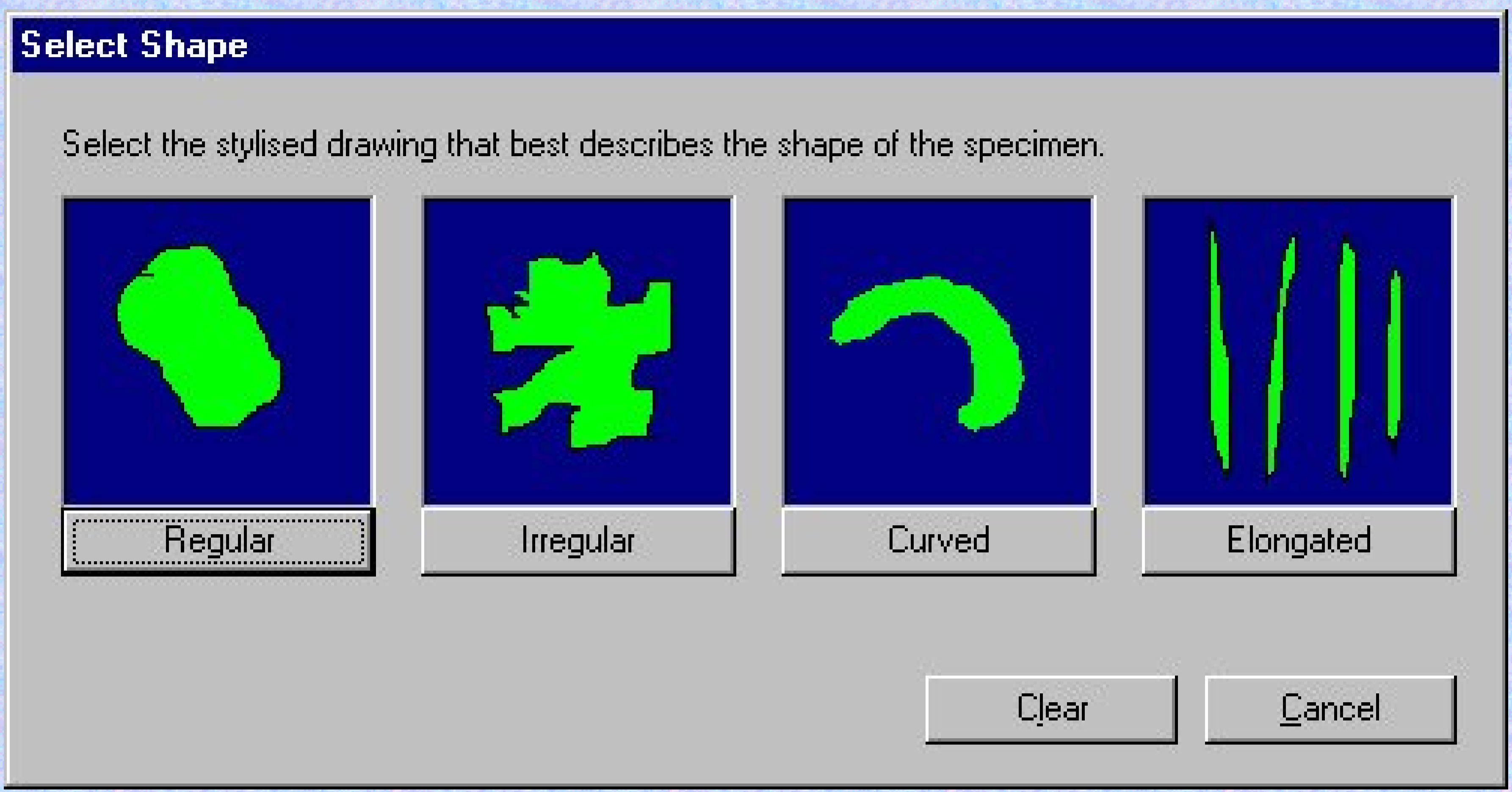
- To assist all EFDC staff in the routine classification of wear debris particles
- To aid the training of new EFDC staff in wear debris classification
- To provide a source of reference material in the form of images and technical information relating to wear debris

SYCLOPS



SYCLOPS Start-up Page

Wear debris classification system. Based on “generic” wear debris database and Baysian belief network. Designed to assist in the objective analysis of debris morphology and relating it to wear modes within oil-wetted systems


Select Shape
Select the stylised drawing that best describes the shape of the specimen.
Regular
Irregular
Curved
Elongated
Clear
Cancel

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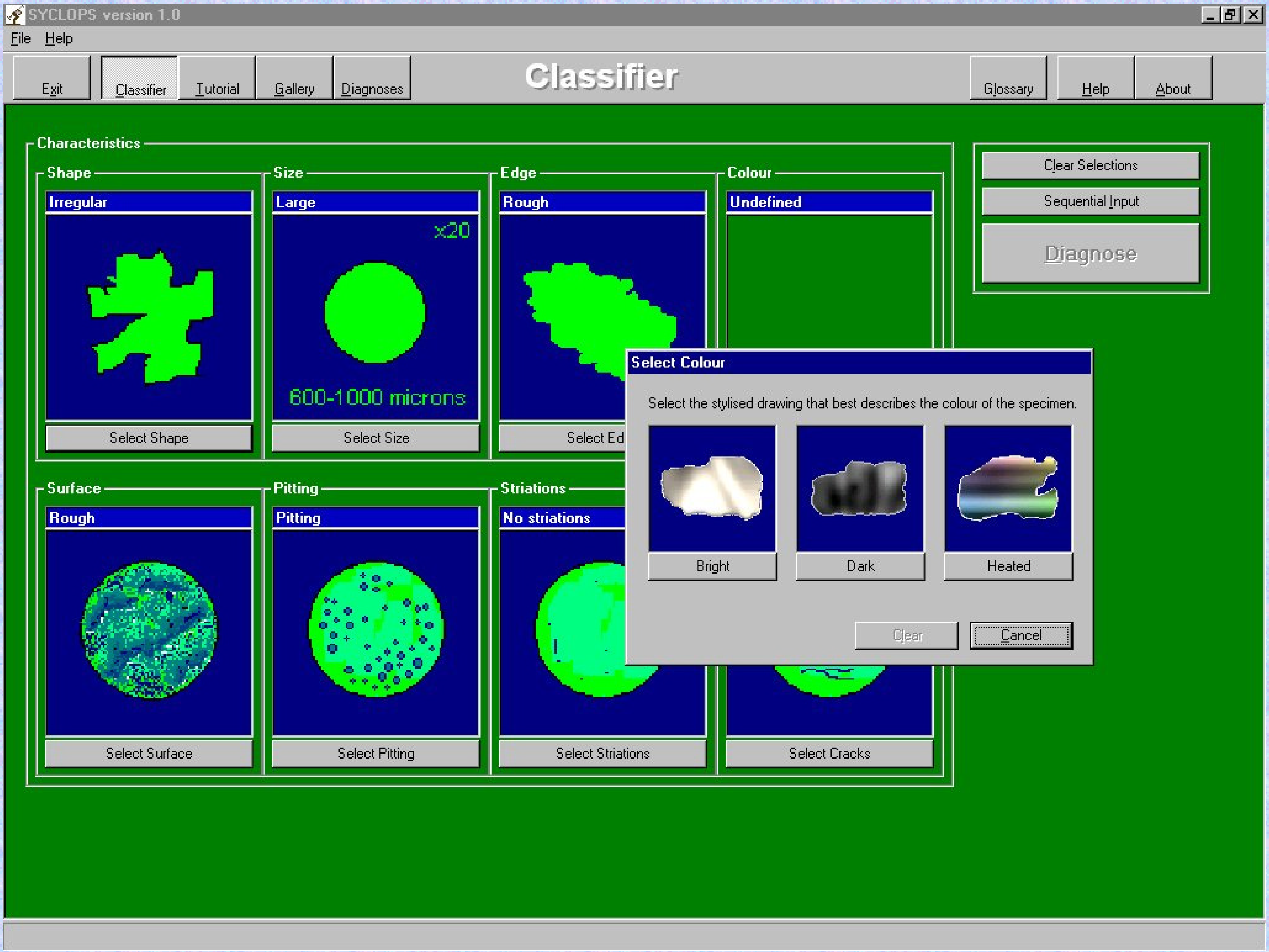
SYCLOPS version 1.0
File
Help
Exit
Classifier
Tutorial
Gallery
Diagnoses
Classifier
Glossary
Help
About
Characteristics
Shape
Irregular
Select Shape
Size
Large
x20
600-1000 microns
Select Size
Edge
Rough
Select Ed
Colour
Undefined
Clear Selections
Sequential Input
Diagnose
Surface
Rough
Select Surface
Pitting
Pitting
Select Pitting
Striations
No striations
Select Striations
Select Cracks
Select Colour
Select the stylised drawing that best describes the colour of the specimen.
Bright
Dark
Heated
Clear
Cancel

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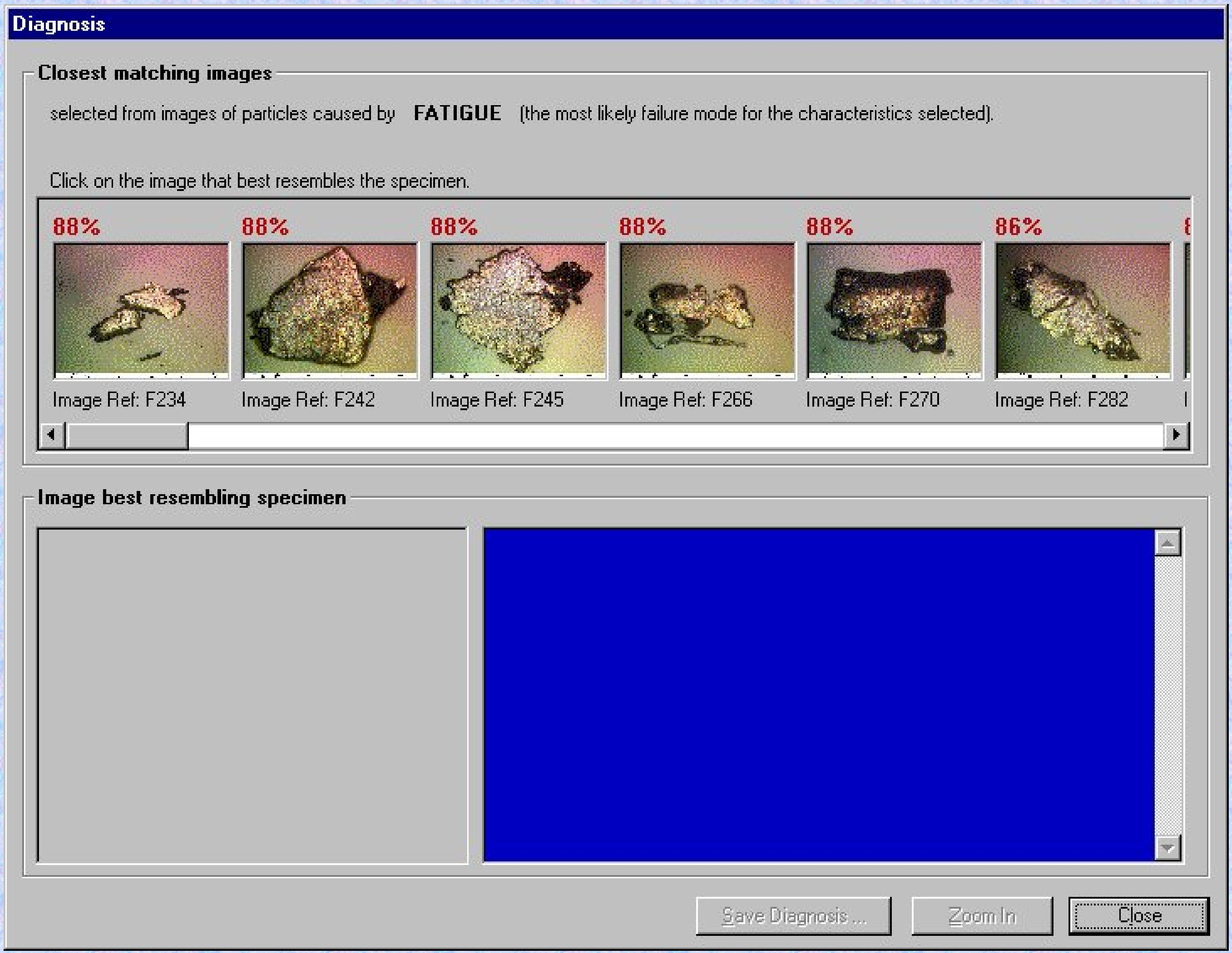
Diagnosis
Closest matching images
selected from images of particles caused by FATIGUE (the most likely failure mode for the characteristics selected).
Click on the image that best resembles the specimen.
88%
Image Ref: F234
88%
Image Ref: F242
88%
Image Ref: F245
88%
Image Ref: F266
88%
Image Ref: F270
86%
Image Ref: F282
Image best resembling specimen
Save Diagnosis ...
Zoom In
Close

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Diagnosis

Closest matching images

selected from images of particles caused by **FATIGUE** (the most likely failure mode for the characteristics selected).

Click on the image that best resembles the specimen.

92% 89% 89% 89% 89% 89%

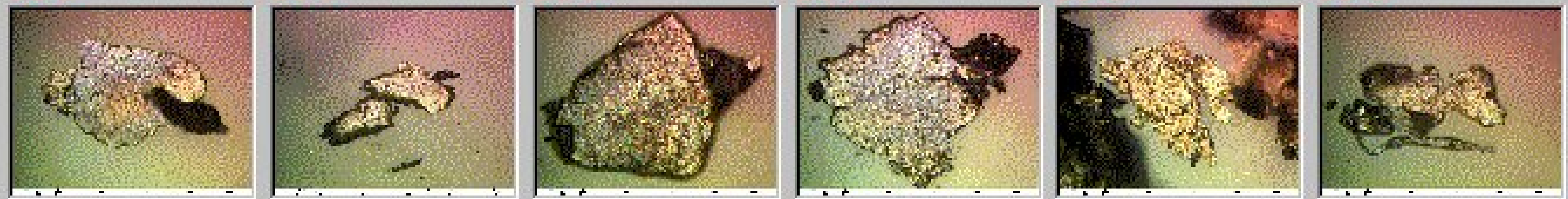
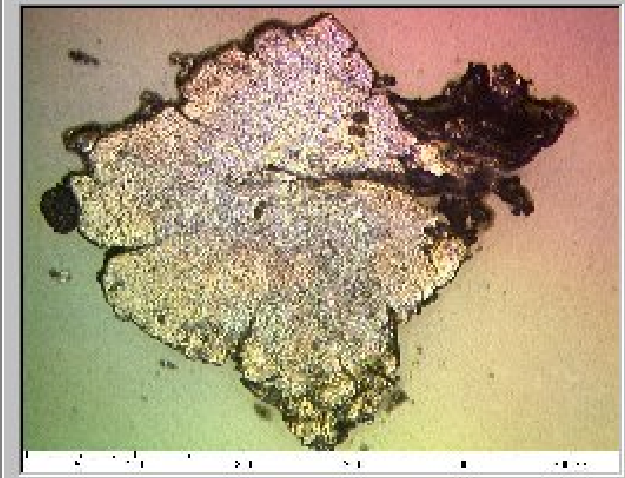


Image Ref: F250 Image Ref: F234 Image Ref: F242 Image Ref: F245 Image Ref: F254 Image Ref: F266

Image best resembling specimen (Image Ref: F245)



Fatigue:

Removal of particles detached by fatigue arising from cyclic stress variations. Within any mixture of fatigue debris, the ratio of large to small particles is indicative of the severity of the failure. Recognition of fatigue debris originating from bearings, gears and shafts is important, as total failure of these components can be catastrophic. Components of this type are manufactured from high-grade steel, which has a fine crystalline structure and high standard of surface finish. These metallurgical characteristics are an aid to the visual identification of the source of fatigue debris.

Save Diagnosis ... Zoom In Close

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Summary of SYCLOPS Project

The SYCLOPS system developed based on a "generic" database of wear debris and a Baysian belief network

SYCLOPS has three main functions - Classifier, Tutorial and Gallery aimed at users of differing levels of experience

Positive results from field trials of SYCLOPS showing initial aims of the project achieved

Version 1.1 is being developed and work has started on a platform specific database

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Other Projects

Collaborative programme with the Naval Research Laboratories, Washington DC to develop a high speed camera for LaserNet on-line debris monitor

Method development for LaserNet Fines off-line debris monitor for testing by the RAF

Evaluation of inductive and electro-static debris sensors

Evaluation of ferro-magnetic debris measuring equipment

Development of COAP III data-management system

Laboratory method development for oil, fuel and debris analysis

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